

UV Coatings, Polarization, and Coronagraphy

Matthew R. Bolcar, Manuel Quijada, Garrett West (GSFC)

Bala Balasubramanian, John Krist, Stefan Martin (JPL)

Derek Sabatke (BATC)

Objectives

- Review of UV coatings and state-of-the-art
- Review of polarization aberration and the impact on coronagraphy
- Recent study results
 - HabEx
 - LUVOIR
- Work to be done

Objectives

- Review of UV coatings and state-of-the-art
- Review of polarization aberration and the impact on coronagraphy
- Recent study results
 - HabEx
 - LUVOIR
- Work to be done

UV Coatings

- Sensitivity in the UV requires aluminum-coated mirrors

UV Coatings

- Sensitivity in the UV requires aluminum-coated mirrors
- Aluminum oxidizes nearly instantly upon exposure to air (even at very low pressures)
 - Oxidation layer reduces UV reflectivity

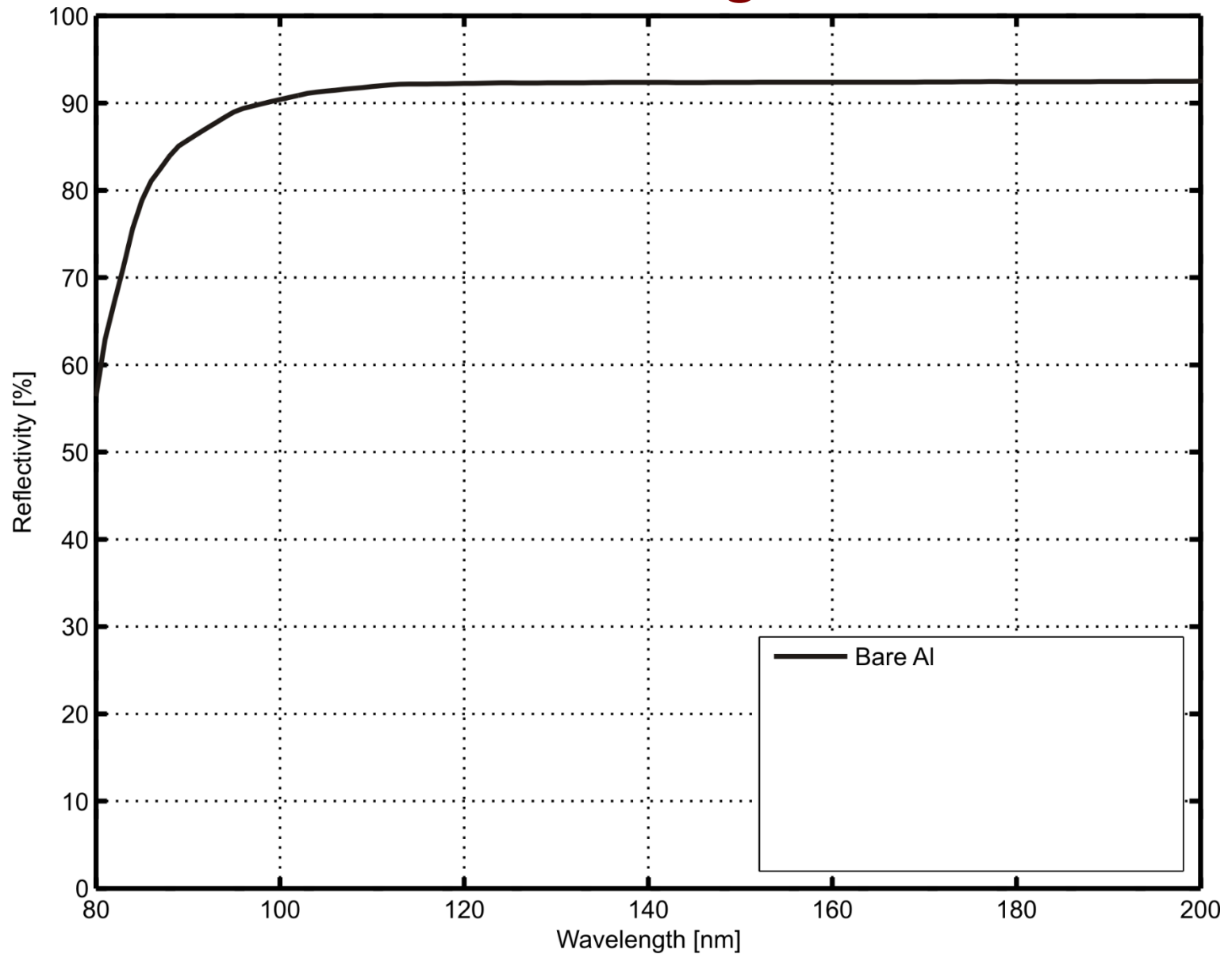
UV Coatings

- Sensitivity in the UV requires aluminum-coated mirrors
- Aluminum oxidizes nearly instantly upon exposure to air (even at very low pressures)
 - Oxidation layer reduces UV reflectivity
- Protective overcoats are used to prevent oxidation
 - Commonly fluoride overcoats, such as MgF_2 , LiF , or AlF_3
 - Provide high reflectivity for wavelengths as short as ~ 110 nm
 - Shortward of 110 nm, reflectivity depends on material and deposition process

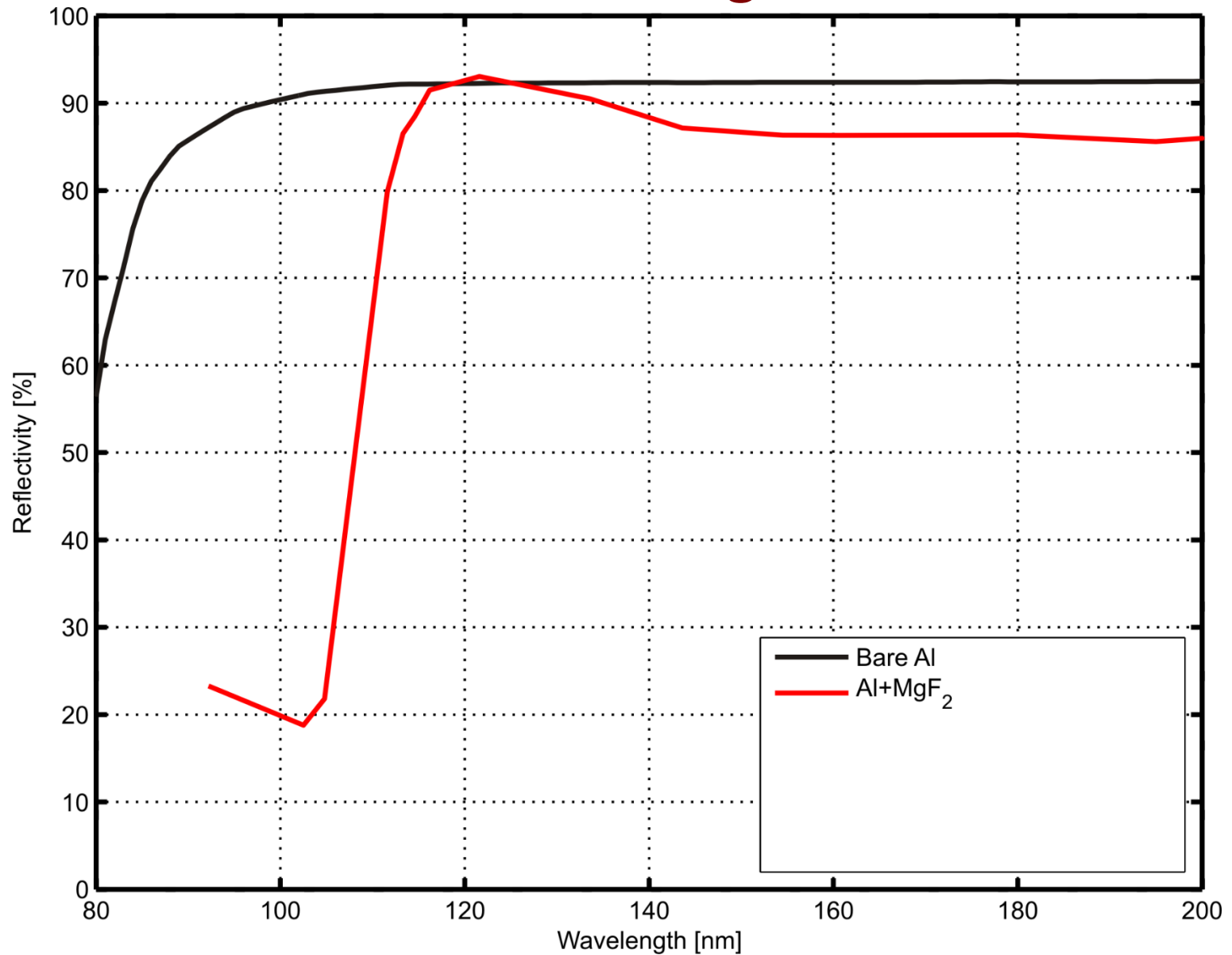
UV Coatings

- Al + MgF₂
 - New “hot” deposition process heats substrate to 220° C
 - Improved reflectivity (> 85%) above 120 nm
 - Cutoff occurs around 115 nm with limited reflectivity shortward
 - ~20% reflectivity at 100 nm
- Al + LiF
 - Lower cutoff than MgF₂, achieving 80% reflectivity as low as ~105 nm
 - LiF is hygroscopic
 - Performance degrades with exposure to water vapor in air
 - Would require dry purge on mirrors during ground operations, OR
 - Requires an additional protective overcoat which can further suppress reflectivity
- Al + AlF₃
 - Promising new coating with low cutoff like LiF, and stability of MgF₂

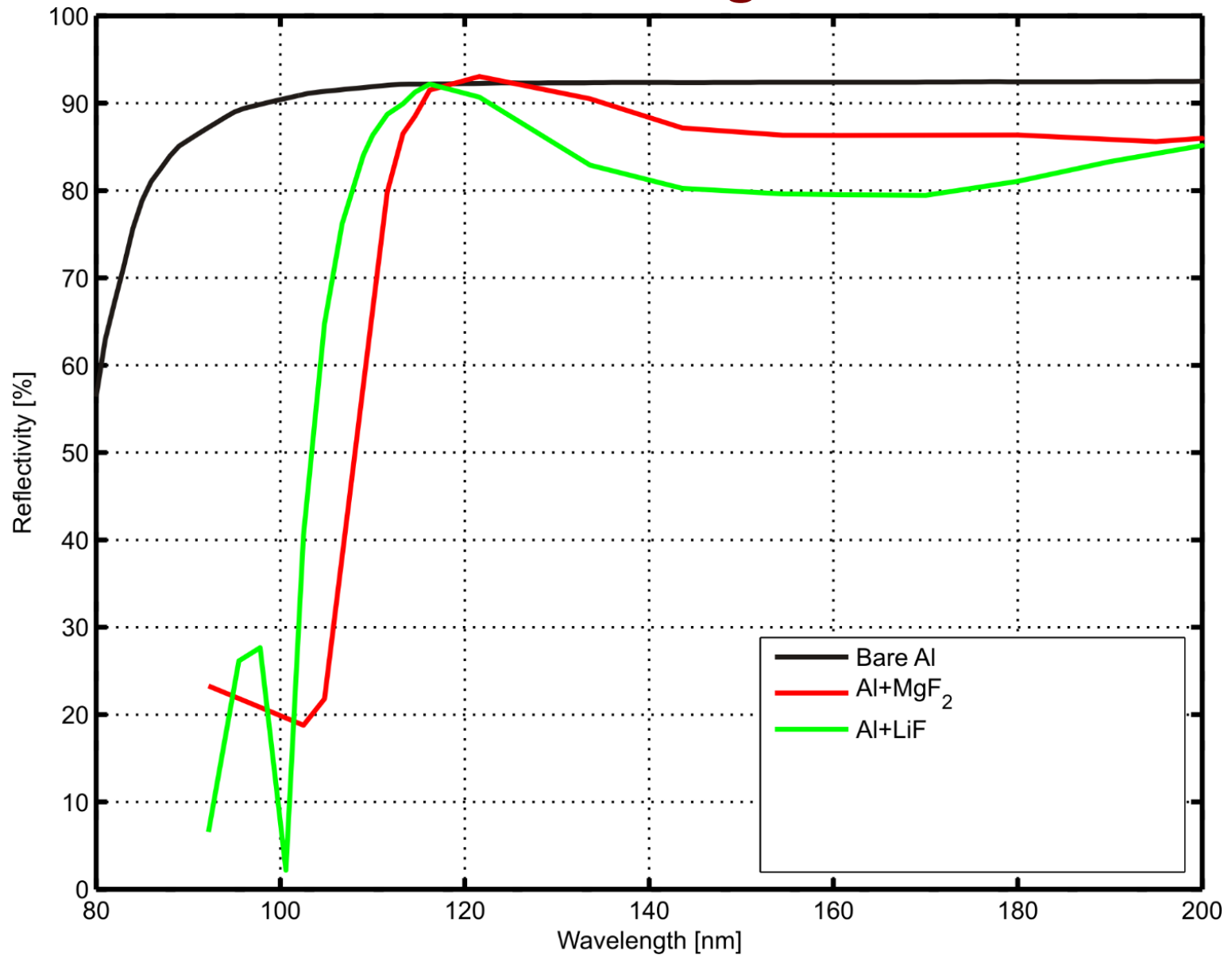
UV Coatings



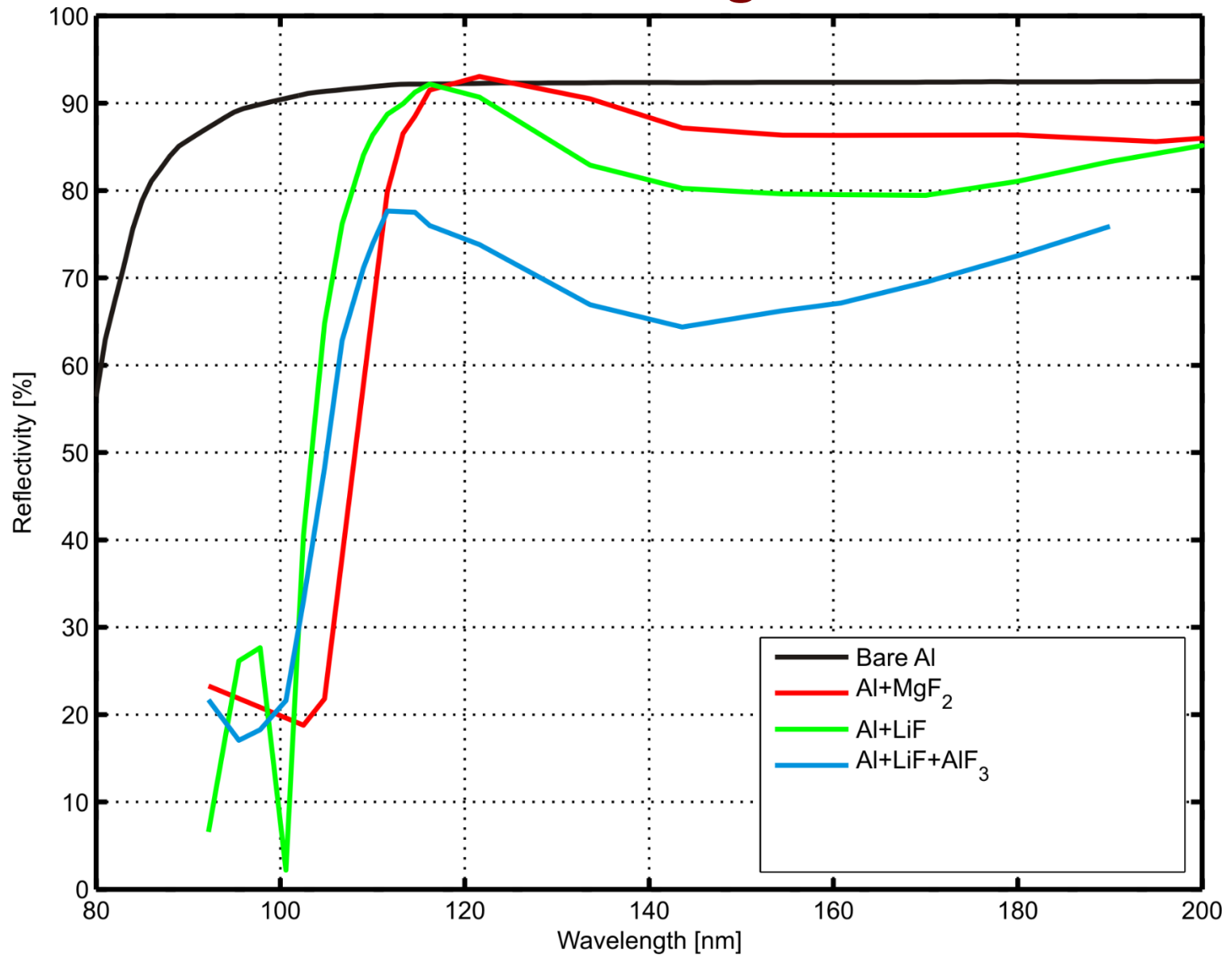
UV Coatings



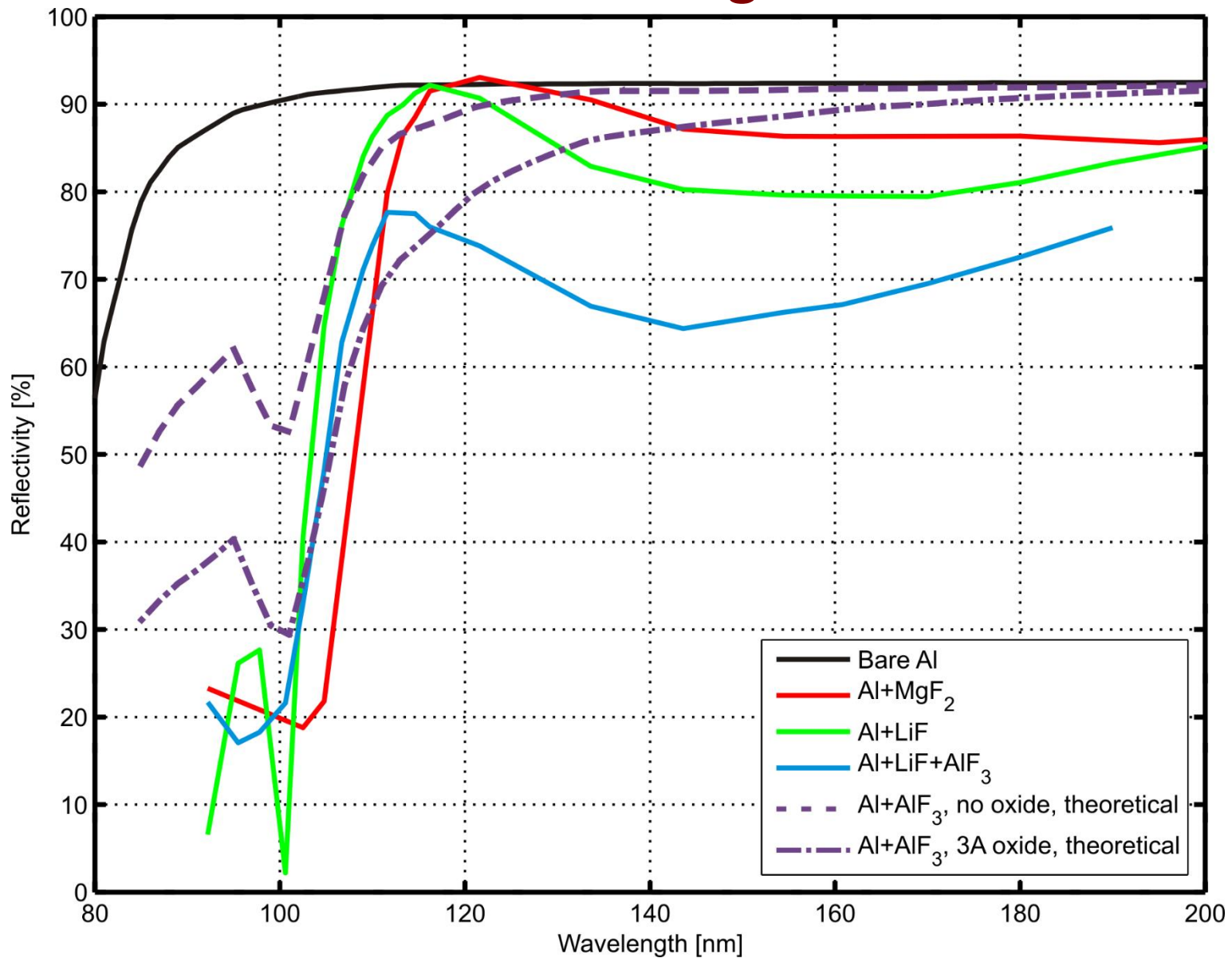
UV Coatings



UV Coatings



UV Coatings



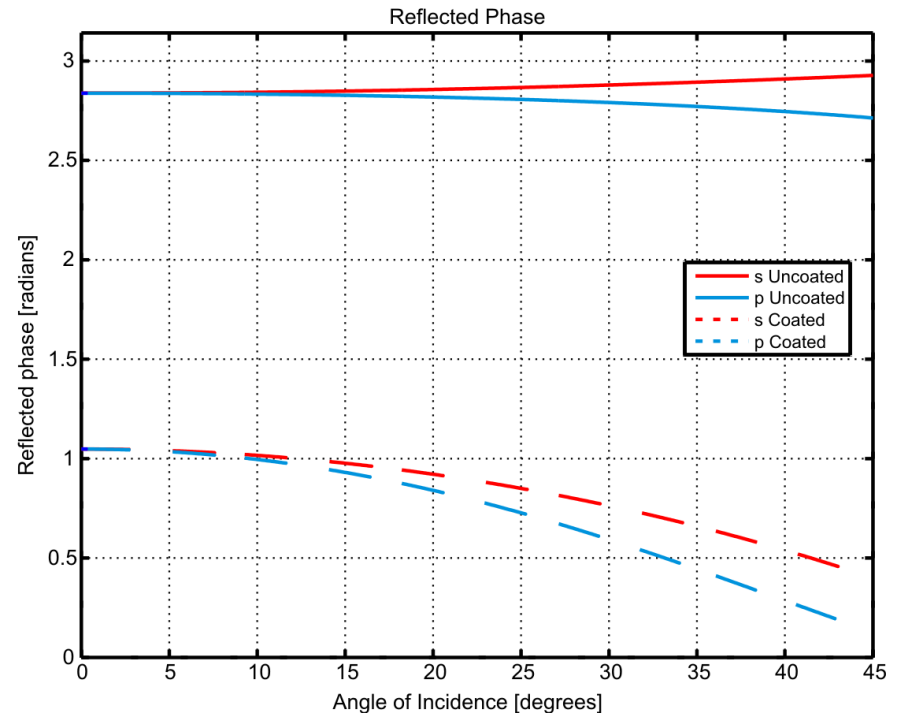
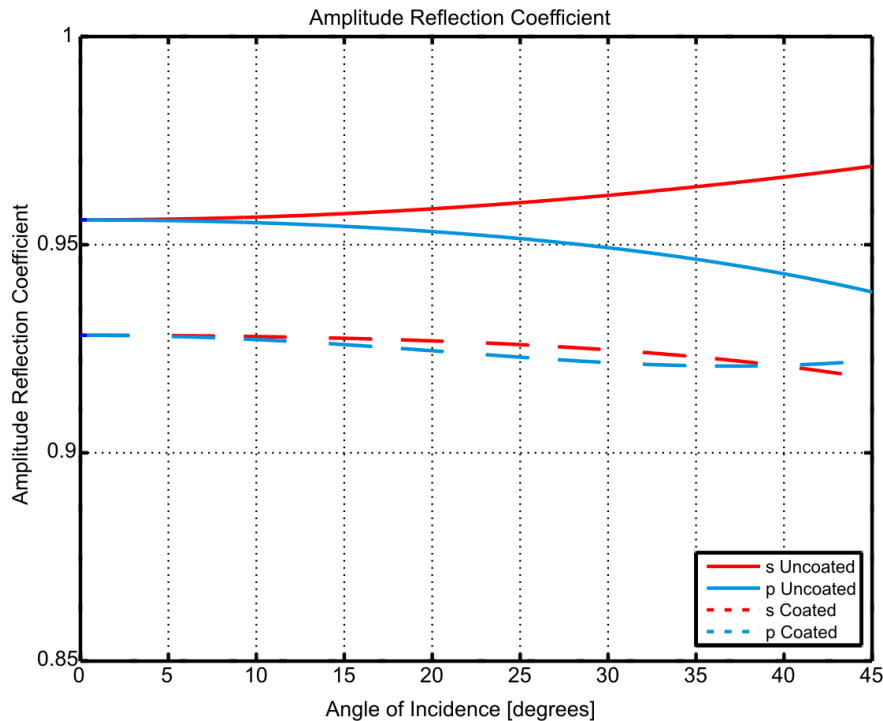
Objectives

- Review of UV coatings and state-of-the-art
- Review of polarization aberration and the impact on coronagraphy
- Recent study results
 - HabEx
 - LUVOIR
- Work to be done

How Coatings Affect Polarization

- Terminology:

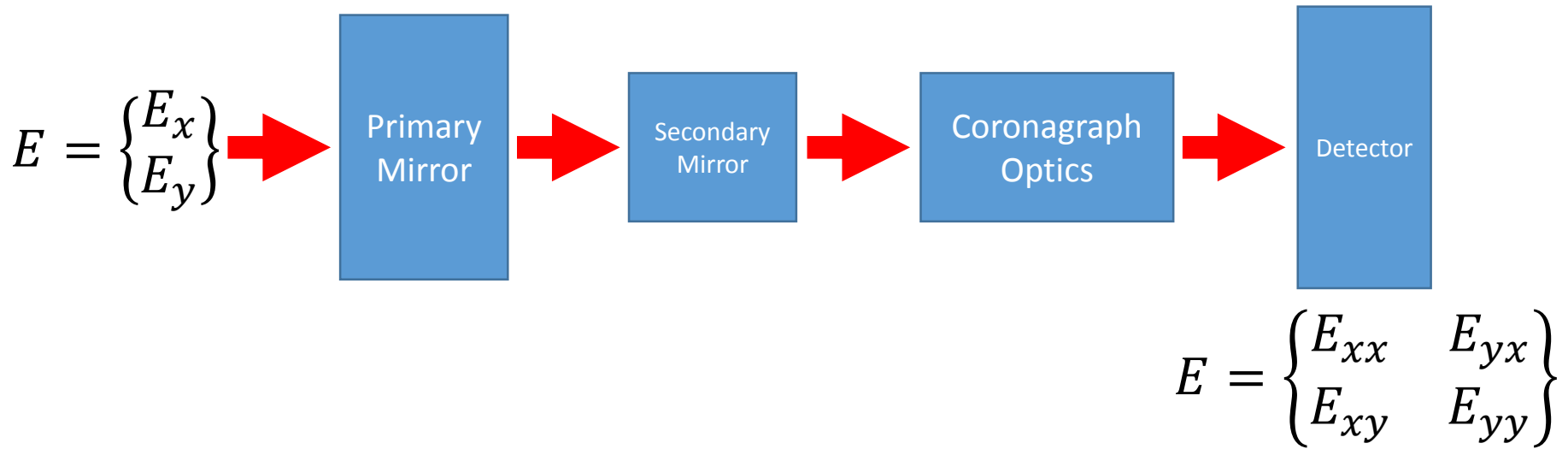
- Diattenuation*: when each polarization state see a different amplitude upon reflection
- Retardance*: when each polarization state sees a different phase upon reflection



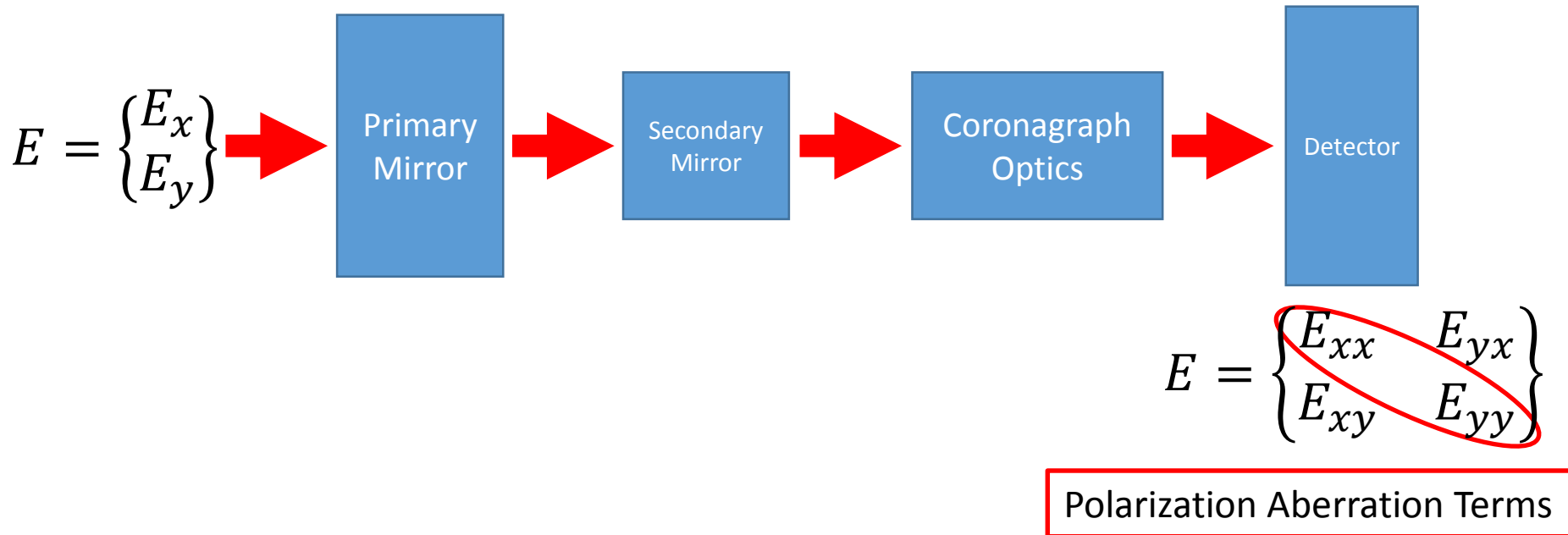
How Coatings Affect Polarization

- There are two ***mechanisms*** of affecting the polarization-dependent amplitude and phase
- ***Polarization Aberration:***
 - Each polarization state acquires a different amplitude and wavefront error as it traverses the system
- ***Cross-polarization Leakage:***
 - Some of each polarization state “leaks” into the orthogonal polarization state
- Net result is ***four*** incoherent (i.e. independent, uncorrelated) electric fields that must be corrected by the coronagraph

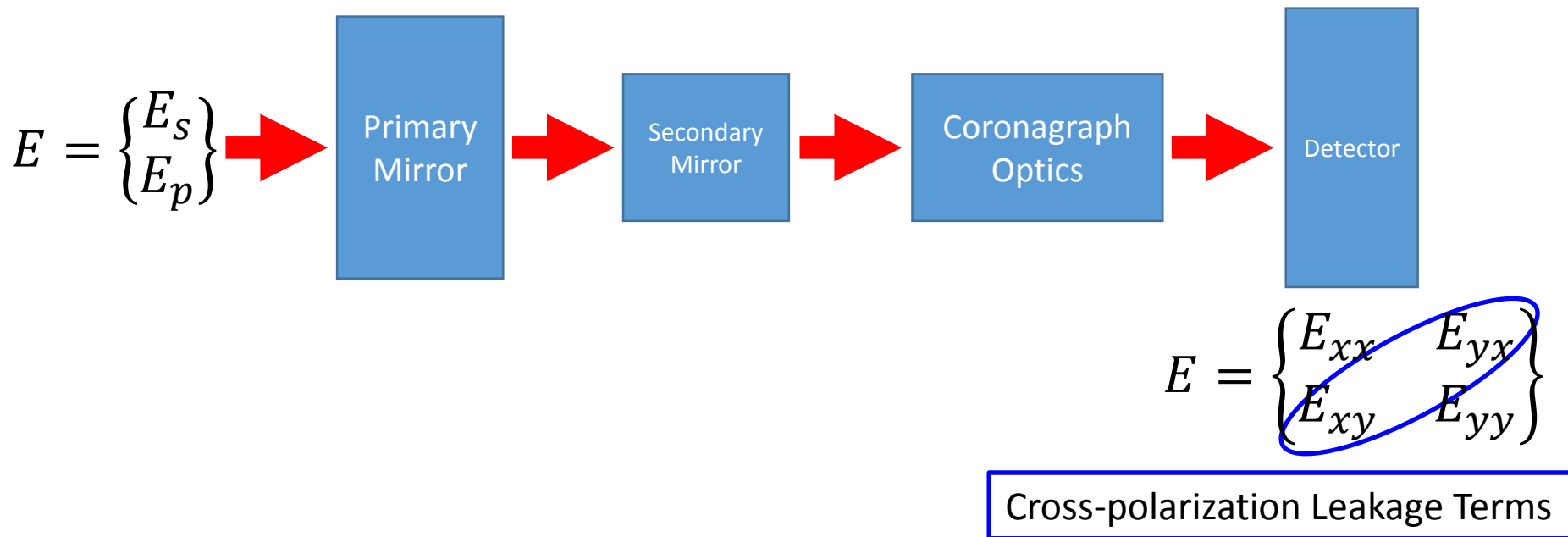
Example:



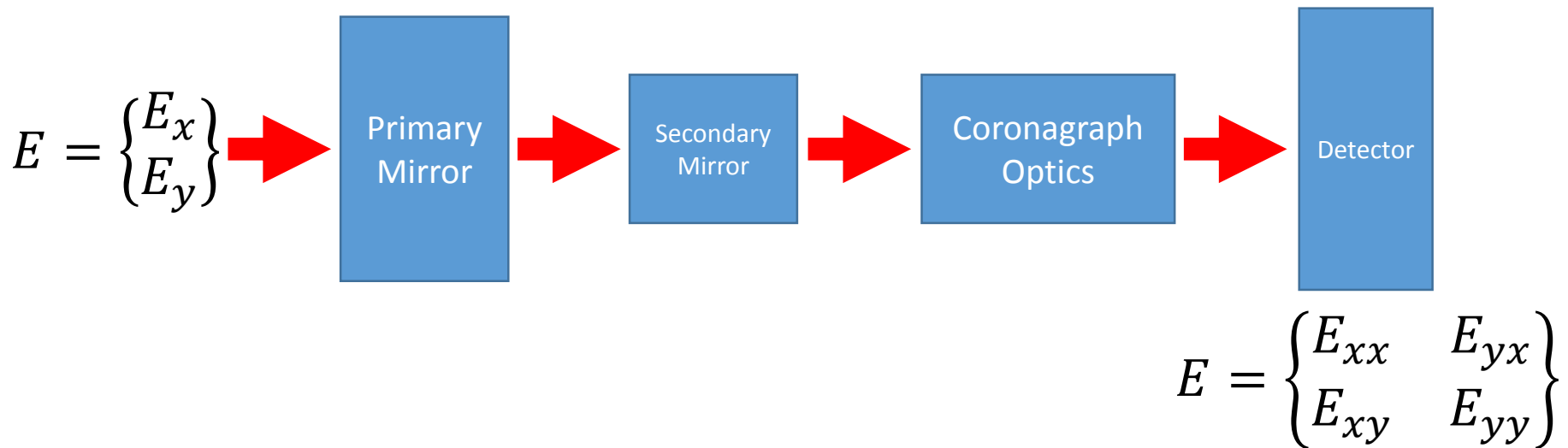
Example:



Example:

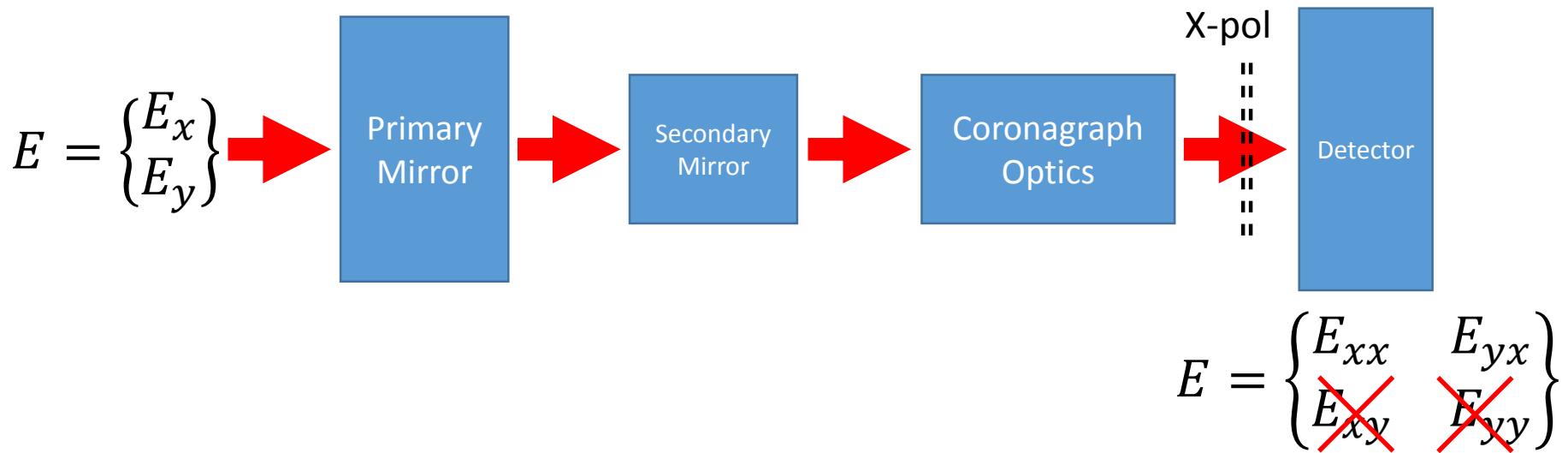


Example:



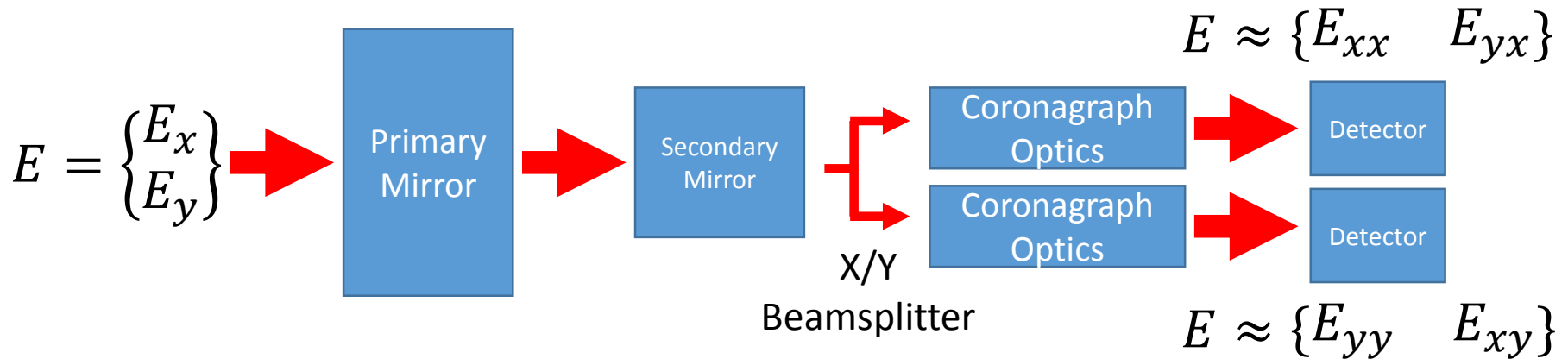
- Four incoherent (uncorrelated), aberrated fields
- If we do nothing:
 - Coronagraph senses and corrects the average electric field
 - Uncorrected portion contributes to contrast leakage

Potential Solution #1:



- Filter polarization at detector plane
- Image is constructed of only “x” polarization components
- Again, coronagraph senses and corrects the average of the remaining terms
- $E_{xx} \gg E_{yx}$ so we get good, but imperfect correction
- But you lose 50% of the light at the detector

Potential Solution #2:



- Split polarizations before entering separate coronagraphs
- Still sensing average of primary and cross-polarization fields, so correction is good, but imperfect
- Retain 100% of the light
- Requires 2x coronagraphs (2x optics, 2x detectors, 2x DMs)

Other Mitigation Strategies

- Limit angles-of-incidence (AOI):
 - Slower primary and secondary mirror F/#'s
 - Avoid flat-fold mirrors at high AOI
 - Can be used in “crossed-pairs” to cancel each other out
 - Creates “long” optical systems which makes packaging and stability difficult

Other Mitigation Strategies

- Limit angles-of-incidence (AOI):
 - Slower primary and secondary mirror F/#'s
 - Avoid flat-fold mirrors at high AOI
 - Can be used in “crossed-pairs” to cancel each other out
 - Creates “long” optical systems which makes packaging and stability difficult
- Optimize coatings:
 - Simultaneously optimizing coating properties/prescription with the optical design can minimize polarization aberration effects

Other Mitigation Strategies

- Limit angles-of-incidence (AOI):
 - Slower primary and secondary mirror F/#'s
 - Avoid flat-fold mirrors at high AOI
 - Can be used in “crossed-pairs” to cancel each other out
 - Creates “long” optical systems which makes packaging and stability difficult
- Optimize coatings:
 - Simultaneously optimizing coating properties/prescription with the optical design can minimize polarization aberration effects
- Polarization compensating components:
 - Investigate active or passive devices that may be able to compensate polarization aberrations
 - Liquid crystals, nonlinear devices, etc.

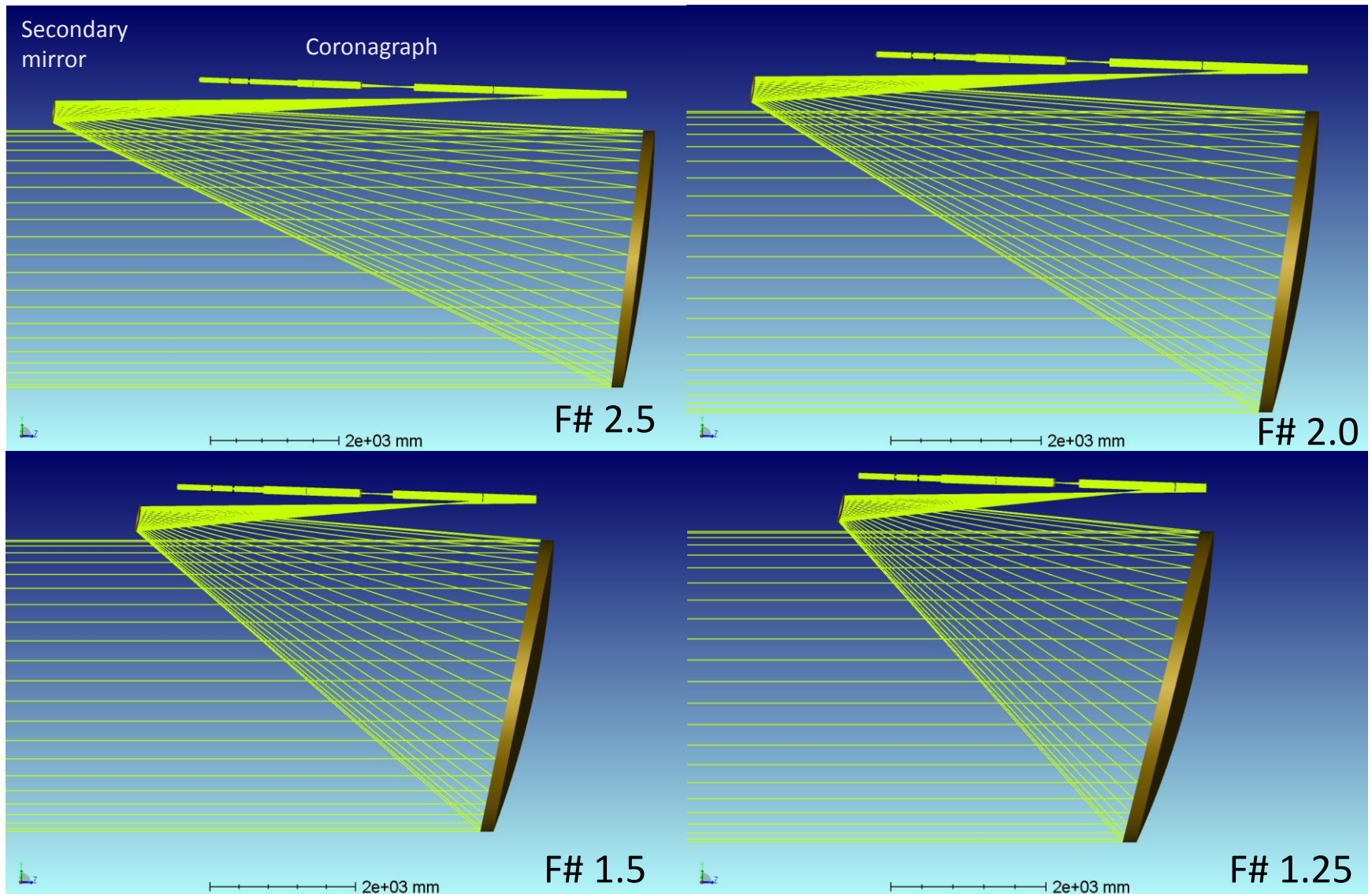
Objectives

- Review of UV coatings and state-of-the-art
- Review of polarization aberration and the impact on coronagraphy
- Recent study results
 - HabEx
 - LUVOIR
- Work to be done

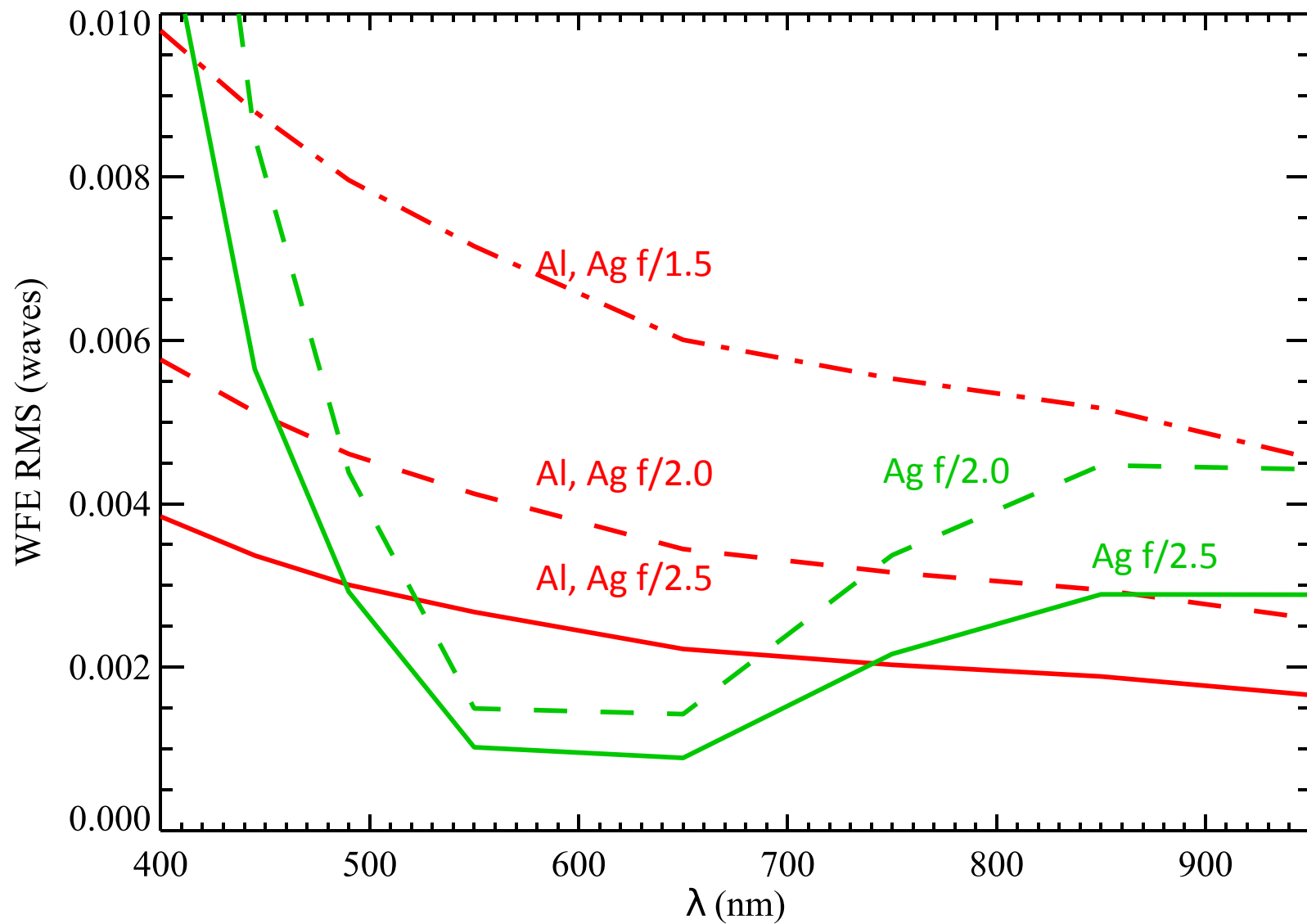
HabEx Polarization Study

- Design based on Exo-C Telescope resized from 1.4 m to 4.0 m diameter
- Telescope is an off-axis, unobscured Ritchey-Chretien design
- Produced a family of designs with primary mirror F#s of 2.5, 2.0, 1.5, 1.25
- For analysis, polarization wavefront analyzed from primary mirror to DM1
- Two scenarios:
 - Coatings on PM, SM, TM are aluminum, with silver on rest of optics, OR
 - All mirrors are silver

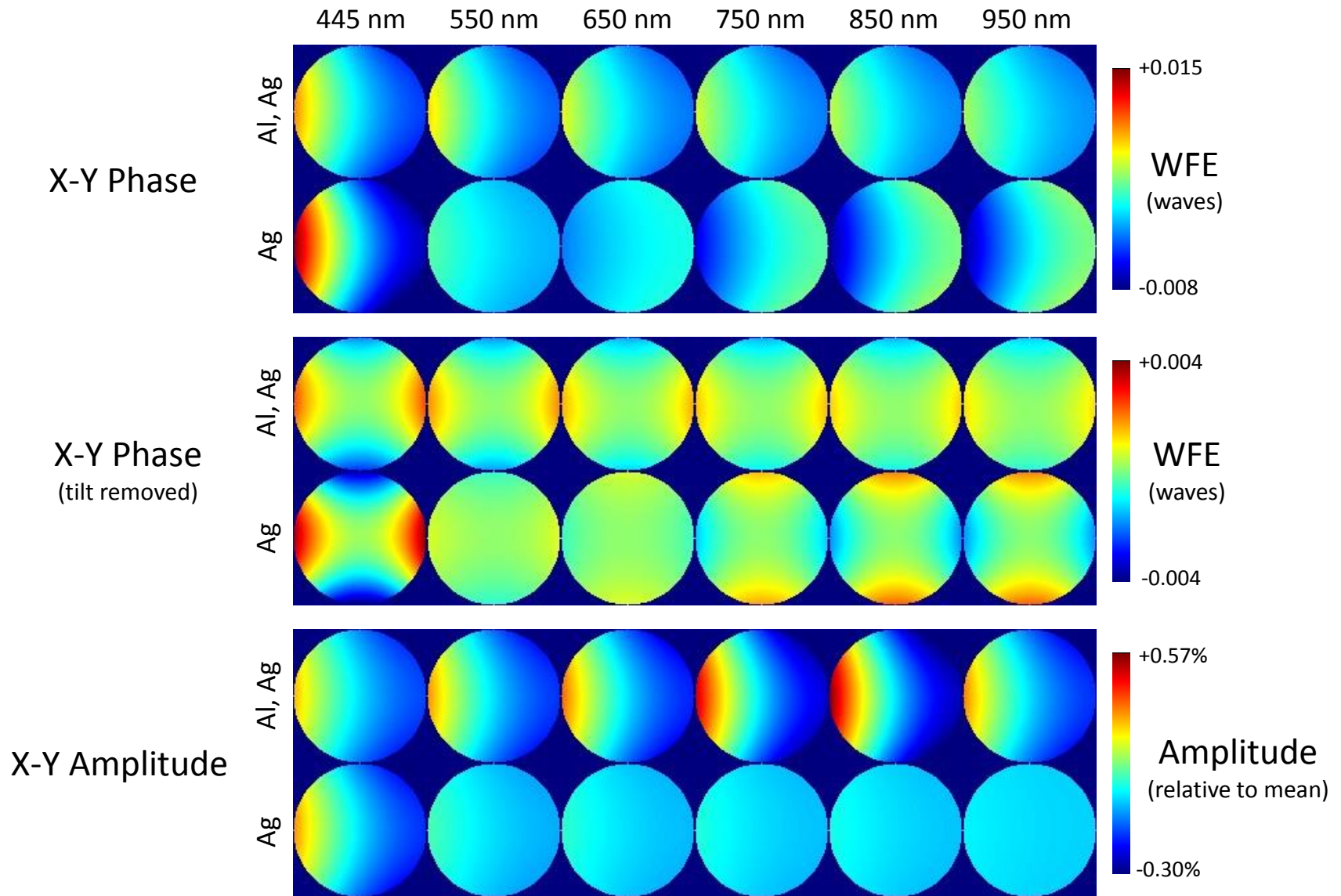
Four designs, Primary F#s 2.5, 2.0, 1.5 and 1.25



X-Y RMS WFE



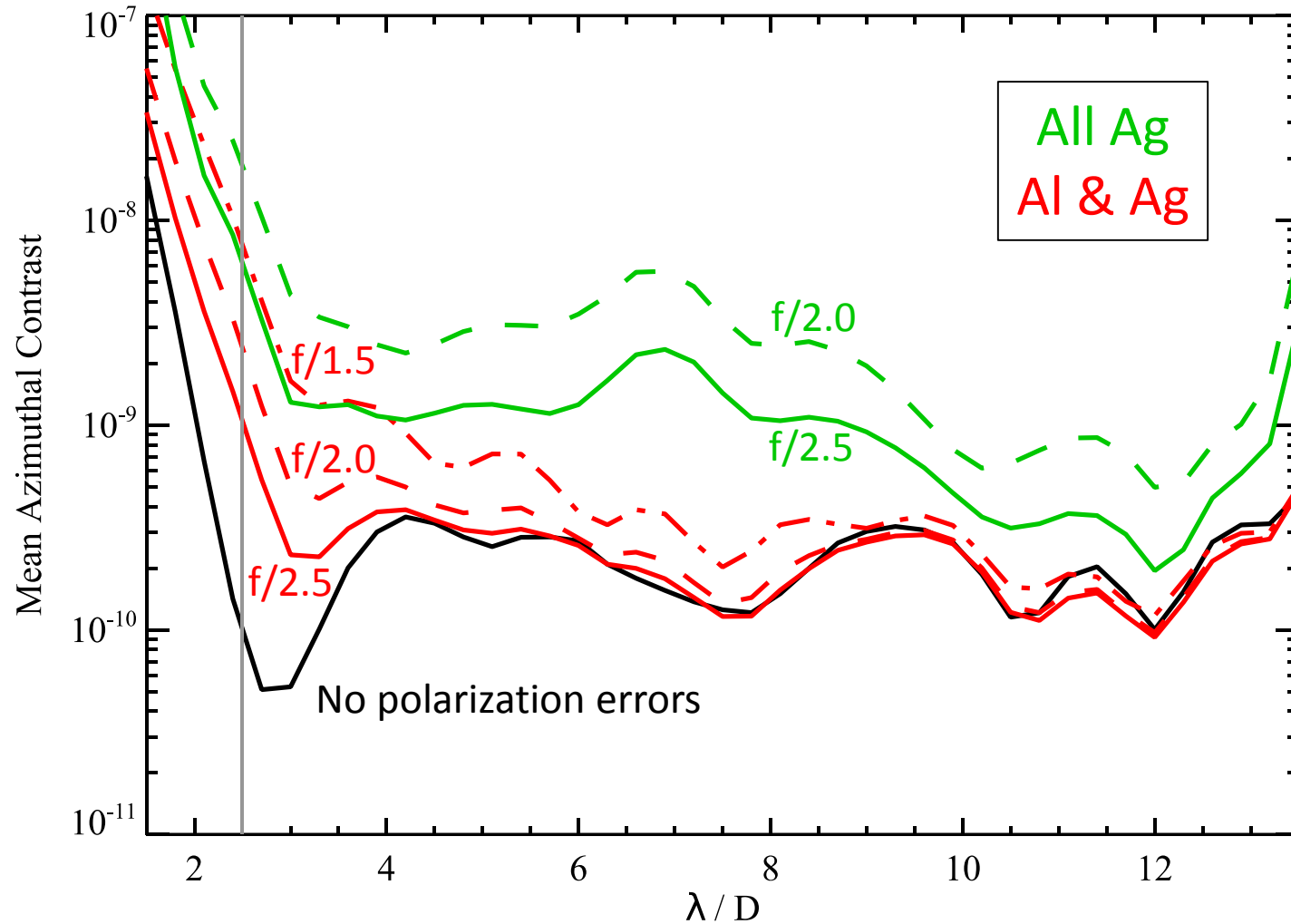
HabEx: X-Y Polarization Wavefront Differences, f/2.5



Tilt & astigmatism are the main polarization aberrations

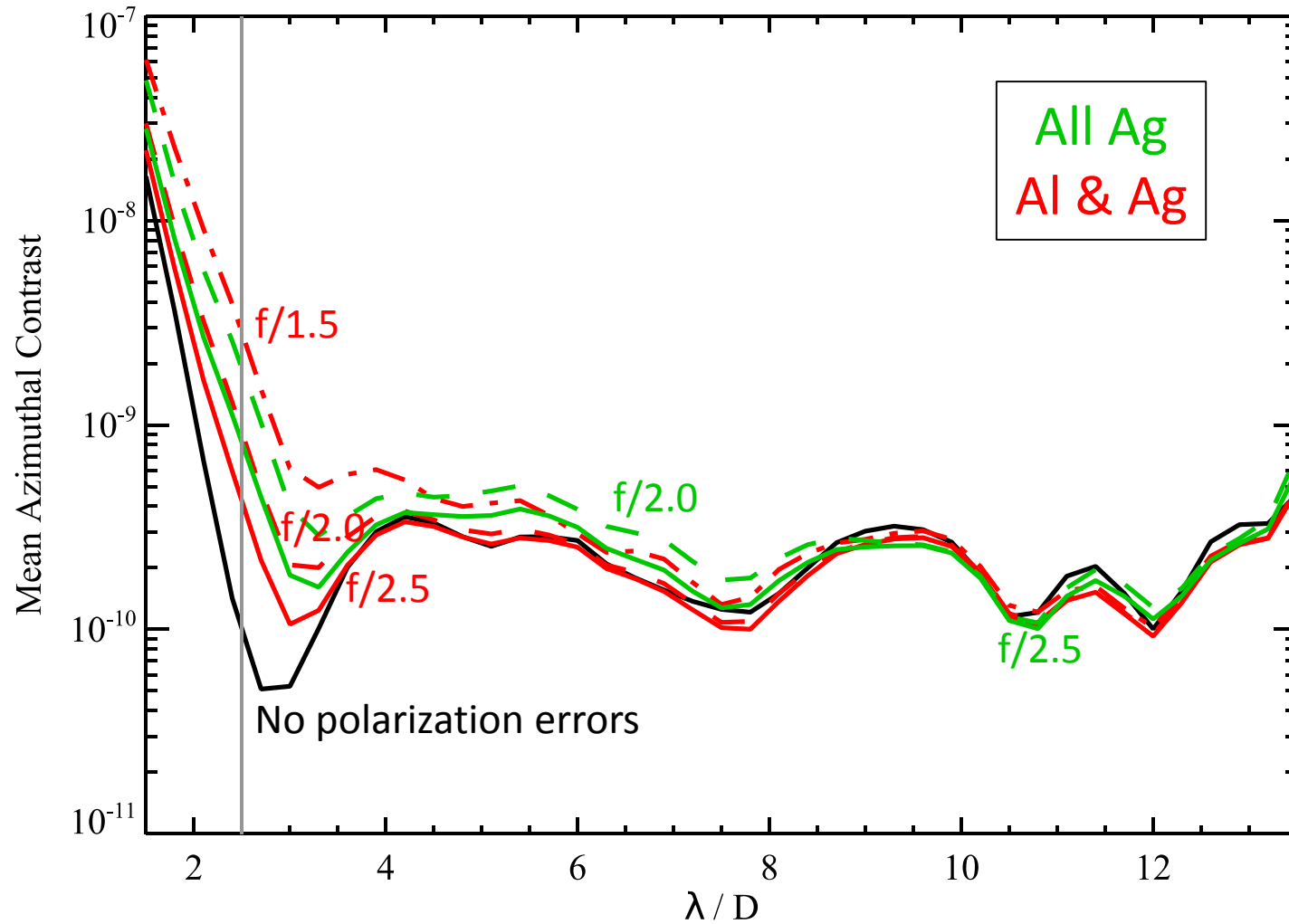
HLC: Post-EFC Contrast: 400-490 nm

All polarizations



HLC: Post-EFC Contrast: 720-880 nm

All polarizations



One Line Summary (courtesy J. Krist):

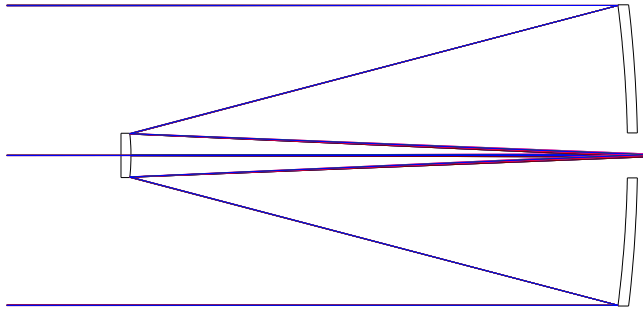
“Use overcoated Aluminum on the 1st three optics.”

LUVOIR Polarization Study

- Four Ritchey-Chretien telescope designs generated:
 - 9m, 12m, 16m on-axis
 - 9m off-axis
- All designs have:
 - 3x3 arcmin diffraction-limited field-of-view
 - Same Primary-to-Secondary Mirror separation
 - Same focal length and hence same plate scale (pixel size on sky)
 - Aluminum-coated mirrors
- Primary mirror F/# varies with design:
 - F/1.1 for 16-m
 - F/1.45 for 12-m
 - F/1.95 for 9-m on-axis
 - F/1.96 for 9-m off-axis

LUVOIR Designs

9-m, F/1.95
Max AOI: 8.51°

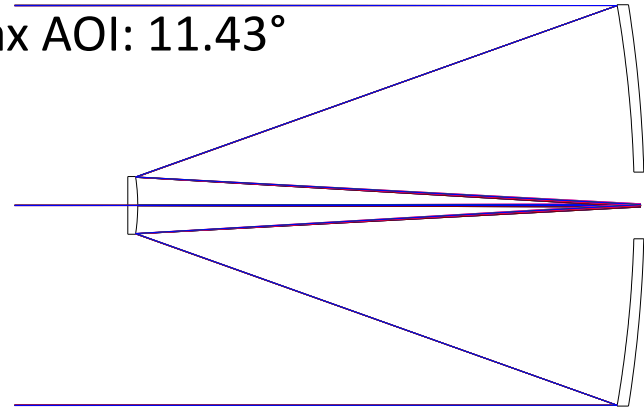


2500.00 MM

LUVOIR OTE RC

Scale: 0.01 GJW 30-Sep-16

12-m, F/1.45
Max AOI: 11.43°

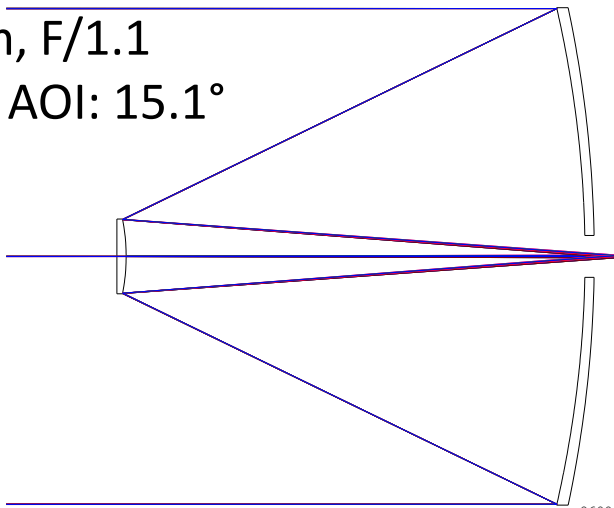


2500.00 MM

LUVOIR OTE RC

Scale: 0.01 GJW 30-Sep-16

16-m, F/1.1
Max AOI: 15.1°

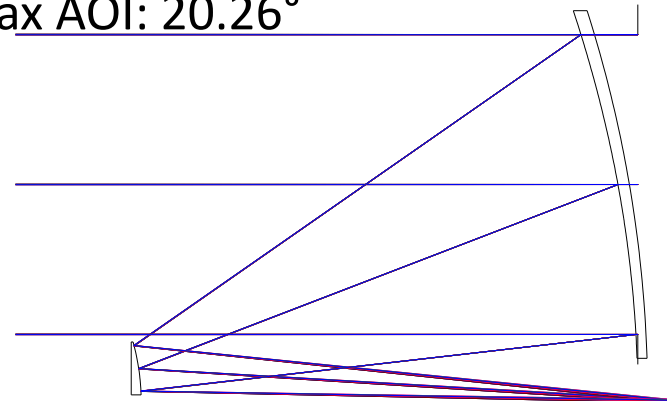


2688.17 MM

LUVOIR OTE RC

Scale: 0.0093 GJW 30-Sep-16

9-m, F/1.96
Max AOI: 20.26°



2500.00 MM

LUVOIR OTE RC

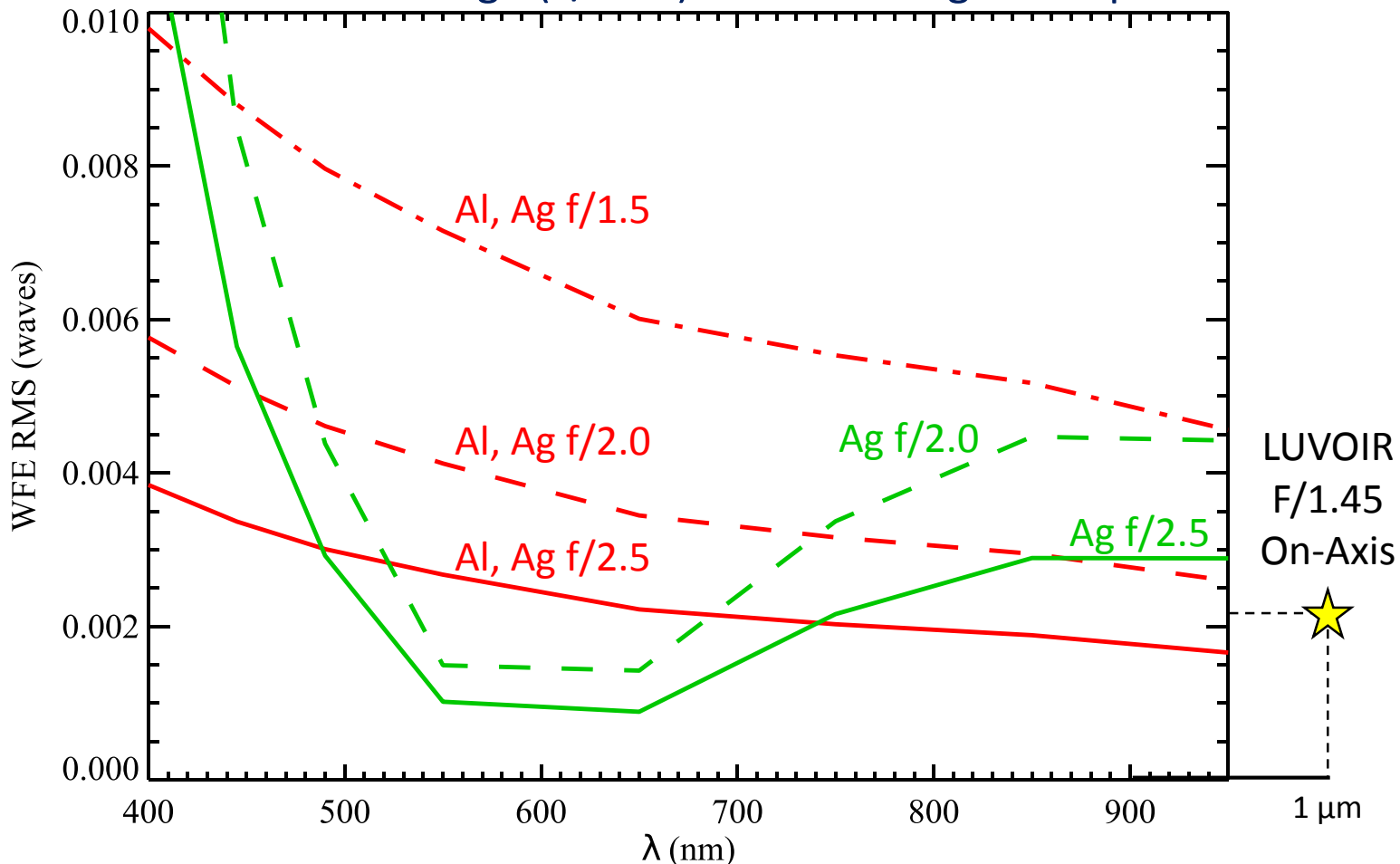
Scale: 0.01 GJW 17-Oct-16

LUVOIR Study is Ongoing

- Preliminary polarization aberration result is available for a single scenario:
 - 12-m on-axis design (F/1.45) at a wavelength of 1 μm

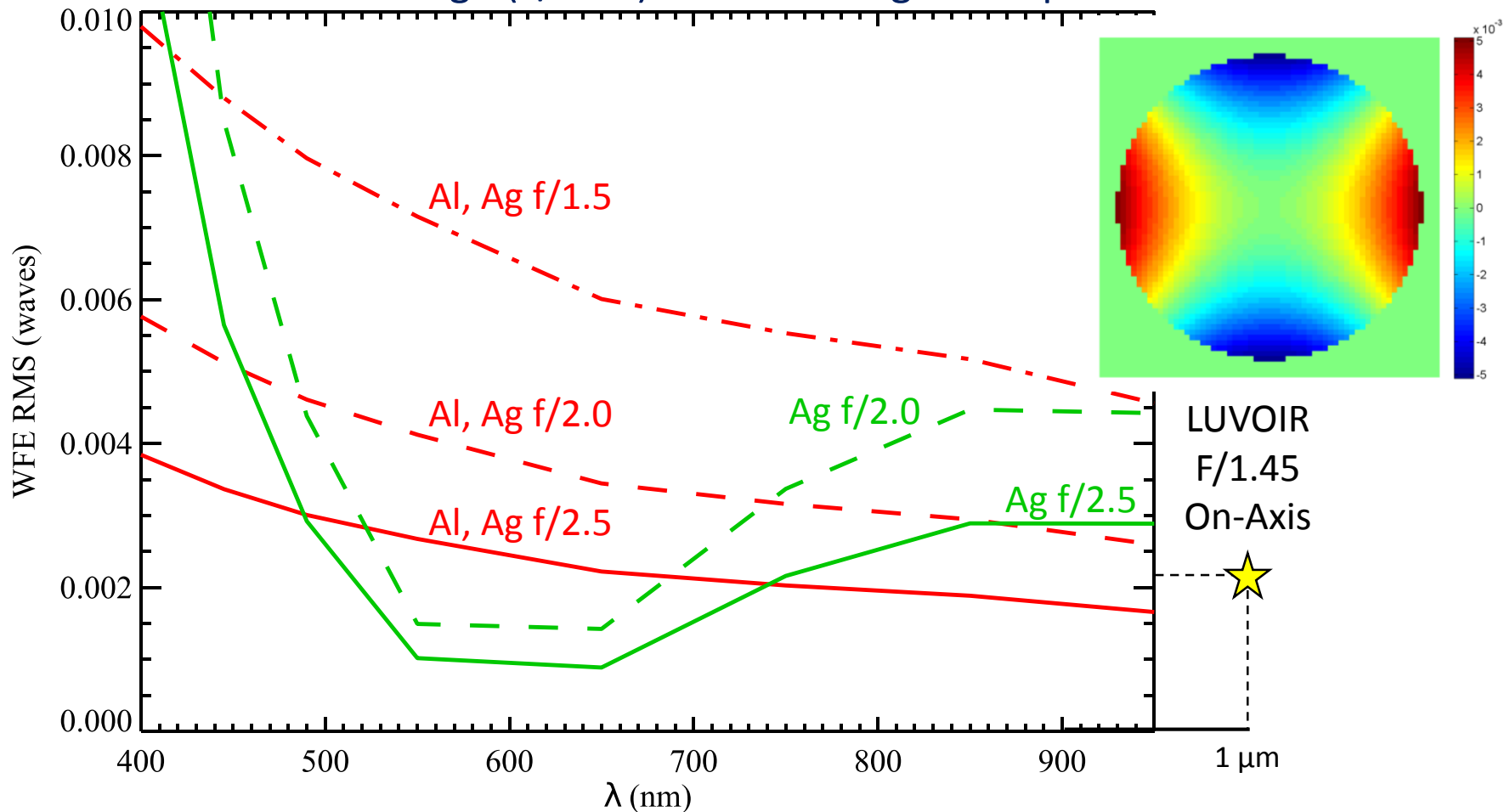
LUVOIR Study is Ongoing

- Preliminary polarization aberration result is available for a single scenario:
 - 12-m on-axis design (F/1.45) at a wavelength of 1 μm



LUVOIR Study is Ongoing

- Preliminary polarization aberration result is available for a single scenario:
 - 12-m on-axis design (F/1.45) at a wavelength of 1 μm



Objectives

- Review of UV coatings and state-of-the-art
- Review of polarization aberration and the impact on coronagraphy
- Recent study results
 - HabEx
 - LUVOIR
- Work to be done

Work to Be Done

- LUVOIR needs to complete analysis of other designs and perform propagation through coronagraph
 - Of specific interest is the on- vs. off-axis trade

Work to Be Done

- LUVOIR needs to complete analysis of other designs and perform propagation through coronagraph
 - Of specific interest is the on- vs. off-axis trade
- Both studies should improve fidelity of coating models
 - Hubble Al+MgF₂ was used for HabEx, and Al+SiO₂ was used for LUVOIR
 - Update with newer MgF₂, LiF, or AlF₃ coating information

Work to Be Done

- LUVOIR needs to complete analysis of other designs and perform propagation through coronagraph
 - Of specific interest is the on- vs. off-axis trade
- Both studies should improve fidelity of coating models
 - Hubble Al+MgF₂ was used for HabEx, and Al+SiO₂ was used for LUVOIR
 - Update with newer MgF₂, LiF, or AlF₃ coating information
- Investigate optimizing coatings to balance/minimize polarization aberration

Work to Be Done

- LUVOIR needs to complete analysis of other designs and perform propagation through coronagraph
 - Of specific interest is the on- vs. off-axis trade
- Both studies should improve fidelity of coating models
 - Hubble Al+MgF₂ was used for HabEx, and Al+SiO₂ was used for LUVOIR
 - Update with newer MgF₂, LiF, or AlF₃ coating information
- Investigate optimizing coatings to balance/minimize polarization aberration
- If different coronagraph channels will be used to process each polarization orientation separately, need to understand impact of cross-polarization leakage

Summary

- Recent protected-Al coatings deliver high-reflectivity down to 110 nm
 - Performance below 110 nm depends on prescription and deposition processes

Summary

- Recent protected-Al coatings deliver high-reflectivity down to 110 nm
 - Performance below 110 nm depends on prescription and deposition processes
- Both LUVOIR & HabEx are pursuing parametric studies to understand trades with respect to telescope aperture and design

Summary

- Recent protected-Al coatings deliver high-reflectivity down to 110 nm
 - Performance below 110 nm depends on prescription and deposition processes
- Both LUVVOIR & HabEx are pursuing parametric studies to understand trades with respect to telescope aperture and design
- HabEx study shows aluminum coating appears to be better than, or approximately equivalent to, silver coating with respect to polarization